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# UNDERGROUND COAL MINING METHODS TO ABATE WATER POLLUTION: A STATE OF THE ART LITERATURE REVIEW

Larry W. Wilson, et al

West Virginia University

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Environmental Protection Agency

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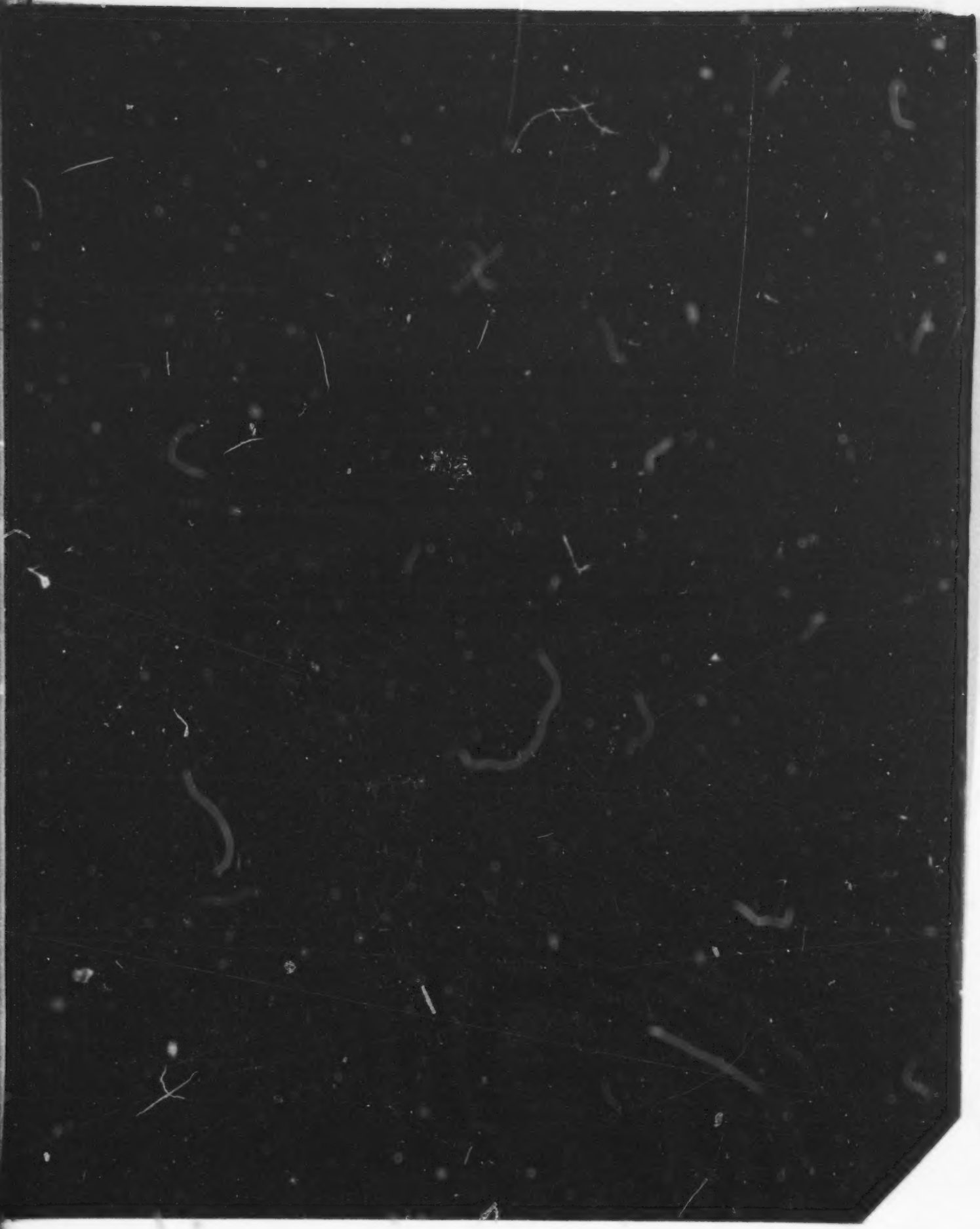

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UNDERGROUND COAL MINING METHODS TO ABATE WATER POLLUTION: A STATE OF THE ART LITERATURE REVIEW,

~~Wilson, L. W.; Matthews, N. J.; Stump, J. E.~~

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This is a review of published information pertaining to the abatement of harmful drainage from underground coal mines. New aspects of two different approaches were considered. Some new physical approaches to the problem of interdicting water entry into coal mines are: (a) land management for surface and sub-surface water diversion, (b) the exploitation of water carrying strata, and (c) new mining methods. Also, chemical approaches to abatement include: (a) the use of silica gel solutions underground to prevent acid formation, (b) the use of inert gas in active mines and (c) the use of new and the refinement of known grouting agents. (Smith-Texas)

*Acid mine water, *Grouting, *Hydrogeology, *Groundwater barriers, *Water management, Groundwater movement, Coal mines, Pollution abatement, Water pollution control, Water table, Land management, *Pumping

*Inert gases, Silica gel

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Richard M. Smith, Jr.

Texas Univ, Austin

# *Underground Coal Mining Methods to Abate Water Pollution:*

# *A State of the Art Literature Review*

by

Coal Research Bureau
West Virginia University
Morgantown, West Virginia 26506

for the

ENVIRONMENTAL PROTECTION AGENCY

Project No. 14010 FKK

December 1970

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## EPA Review Notice

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## ABSTRACT

This review includes published information about the abatement of harmful drainage from underground coal mines. Although much has been written on mine water management, very little literature is available on the specific area of mining to prevent the formation of acid water. The references included in this report, which involve mining engineering and mining oriented hydrology studies, span that period of time when water quantity rather than quality was the major consideration.

Physical approaches to the problem of preventing water entry into coal mines, as a means to broaden water improvement techniques beyond removal and treatment, have only recently been undertaken. Some new approaches to this problem are (a) land management to control surface and subsurface diversion, (b) the skillful and favorable exploitation of water carrying strata, and (c) implementation and innovation of mining methods and techniques which are conducive to improved water quality.

Chemical approaches being considered or presently under investigation involve (a) the use of underground silica gel solutions to prevent the formation of acid mine water, (b) the experimental use of an inert gas atmosphere in active mines to prevent acid water formation and (c) the search for new and the refinement of existing grouting agents.



This report is submitted in partial fulfillment of the requirements of Project No. 14010 FKK under the sponsorship of the Water Quality Office, Environmental Protection Agency and the Coal Research Bureau of West Virginia University.

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# SECTION I

## CONCLUSIONS

1. Mine drainage constitutes surface or ground water which flows from mines or mine sites and is usually characterized by concentrations of acidity or alkalinity.

2. The regional geology controlling the ground water flow pattern in conjunction with the life cycle mining plan can serve as a basis for making decisions about quality of water that can be expected to be encountered.

3. In regard to the prevention and control of acid water formation in underground coal mines, much is left undone in research and education:

   (A) Very little literature is available on this specific subject although much has been written on water management in underground mines.

   (B) Little or nothing is contained in the text books and curricula used in mining departments at colleges and universities with the result that educational offerings may be seriously deficient in these areas.

4. Prohibiting water entry into underground coal mines is the best method of preventing water pollution. Since this is not possible as mining operations are extended, preventing water or oxygen from contacting acid producing material may offer the next best alternative.

5. More emphasis is needed during the mine planning stage on steps to prevent water pollution. Such life cycle considerations as type of mining, sequence of development and spatial configuration as well as the elements of the drainage network and final network organization and extent must be considered.

## SECTION II

## RECOMMENDATIONS

1. Mining to prevent and control underground acid formation should begin with education imparted through:

   (A) Course work at mining schools to teach prospective engineers.

   (B) Training of engineers presently employed in the mining industry through appropriate mining extension courses.

2. Considerable need exists to devote more attention to:

   (A) Hydrogeologic studies of mining areas to enhance the planning of new mines and the abatement program of existing mines.

   (B) Additional research to explore methods of dewatering the strata associated with mining areas.

   (C) Further effort to develop sealants for preventing contact between water or oxygen and the acid producing material associated with the coal seam.



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## SECTION III

## INTRODUCTION

The production of harmful pollutants from coal mines and/or from coal and associated strata has been a recognizable fact in the United States for over two hundred and seventy years. In 1698, Gabriel Thomas observed[1] that the colored water flowing from streams in this country was similar to that which flowed from the coal mines in Wales. Hence, water pollutants such as acid were being produced before any known coal mines were operating in this country. The coal mining industry has contributed to the increase of pollution by exposing large amounts of sulfide materials that enable the reaction of water, oxygen and sulfur containing materials to form acid.

A map of the United States coal fields can be seen on Figure 1. The anthracite regions of Pennsylvania, although small when compared to the total reserves, have produced some of the country's major water problems. The map indicates the extent of bituminous reserves of the Appalachian and midwest regions. Also evident are the bituminous, subbituminous and lignite coal reserves in the west which have recently come into greater demand. Acid mine pollution is encountered in numerous states, but the major problem is found in the Ohio, Susquehanna, and Potomac River basins.[2]

Most coal beds contain some sulfur which may be in the inorganic, sulfate, or sulfide form, and thus have the potential to produce sulfuric acid. However, much of the strata that overlays the coal beds also contains acid neutralizing materials. Therefore, the amount of acid produced depends upon the amount of both acid and alkali materials that dissolve in the water in any given mine.

The common sources of sulfurous material in the seam or surrounding rock are generally called sulfur balls or "nigger heads" by the miners. Sulfur balls that have been observed[3] seem to be equally divided between those containing sulphuritic iron capable of producing sulfuric acid upon oxidation and those that are primarily calcium carbonate. It has been observed in many instances that two types of water, acid and alkaline, are being produced in the same mine. A study of the geological strata and a survey of subsidence, faults and sulfur balls will usually give some indication of why this happens.

The reaction of pyrite ($FeS_2$) with oxygen and water to form ferrous sulfate ($FeSO_4$) and sulfuric acid ($H_2SO_4$) by a series of complex chemical interactions is well documented but not well understood.[4,5] However, it is well known that the reactions to form the acid cannot occur unless all three constituents are present. Since pyrite is inherent in most coal seams and air is needed to sustain the miner, the most logical answer is to eliminate water infiltration into the mine, or to remove it from the mine before acids can form.



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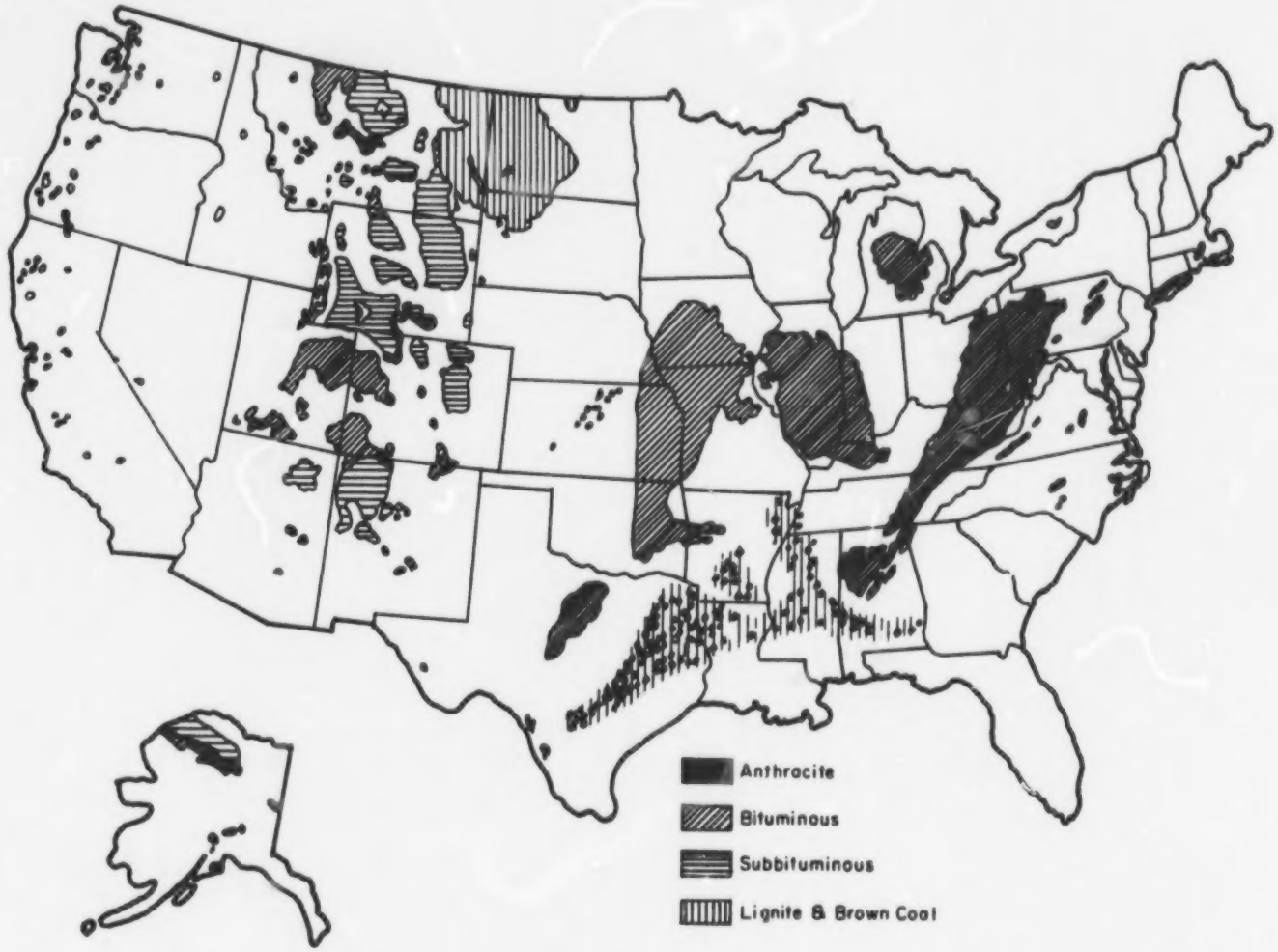


Fig. 1 – Coal Fields of the United States.

The most common method of eliminating water infiltration has been sealing abandoned mines with cement or concrete block. Much success has also been accomplished where the mine was flooded with water preventing oxygen from contacting the pyrite. Those seals which have been placed above the water table have had minimal success, because the strata usually breaths and permits the oxygen supply to replenish. Thus, current methods of using wet seals will not stop pollution entirely, but may, in many cases, be of some help.

This report encompasses a literature survey of acid mine water abatement measures and mining hydrology. Mine water management is examined from the aspects of preventing water entry, preventing formation of acidic waters, underground water treatment, and water removal. Sealing methods and unique methods in deep mines are also discussed. Those areas where further research efforts might be applied are noted in the section on research needs.

This state of the art report completes the goal of Phase I of a project for investigating methods that can be utilized for the reduction of harmful drainage from underground coal mines. Phase II of the program will involve on-site mine visitations to evaluate those practices and techniques which are currently employed, although not necessarily published, in underground coal mines for the prevention or reduction of harmful mine drainage. Phase III of the program will be an evaluation and publication of information obtained during Phase II of the program.

## SECTION IV

## GROUND WATER HYDROLOGY

Underground and strip mining[6,7] produce different hydrologic environments. Many underground mines are below the zone that is completely saturated with water and the mine openings may cause new and continuous contact between sulfurous material and water which flows from the saturated zone to the workings. Strip mines are usually above the zone of continuous saturation and contact between sulfurous material and water is generally restricted to periods of precipitation. A full appreciation of the problem of water pollution caused by drainage from deep mines requires a basic understanding of occurrences and movement of water in the ground and the modes of ground water entrance into mining areas.

### Ground Water Occurrence

The most important factor in ground water occurrence is the surface and sub-surface geology.[8,9,10,11,12] Over most of the earth a zone filled with both air and water (the zone of aeration) overlies a zone completely filled with water (the zone of saturation). The surface between these two zones is the water table and in general the water table conforms to the ground surface topography, (see figure 2). Underground geologic formations may, however, alter this general rule. When water flows through a specific geologic formation bound above and below by impermeable strata, the formation is termed a confined aquifer and the water is termed artesian water. Formations that allow water to flow freely and seek its own level, in response to precipitation and discharge changes, are termed unconfined aquifers.

A special case of unconfined ground water, termed a perched water table, is a saturated zone located above the main body of ground water and separated from it by a zone of impermeable strata, (see figure 3). Strata that will not transmit the flow of water and has no storage capacity is termed an aquiclude[11] (see figure 2).

### Water Movement and Mining

The movement of ground water is usually[13,14] from topographic high elevations to topographic lows, but mining presents a specific set of circumstances in relation to ground water movement, (see figure 4 for graphic illustration).

> "When a shaft is sunk below the natural water table in rock that is reasonably permeable and homogeneous, pumping immediately begins to drain water out of the pores and crevices in the rock. As pumping continues the water level is artificially depressed and assumes much the shape that a stretched membrane would have if one were to punch it downward with a stick. That



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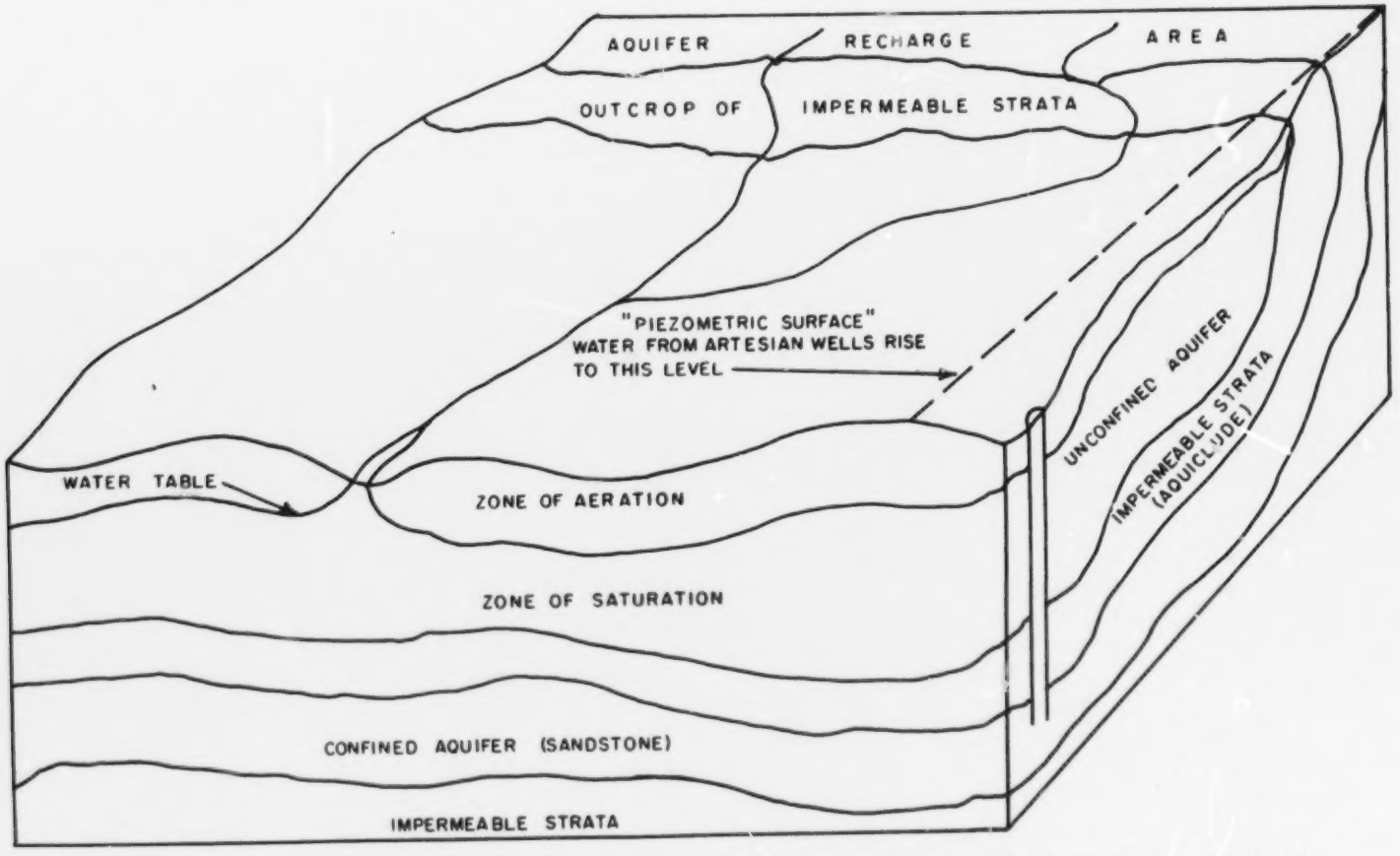


Fig. 2 – Generalized Diagram Showing The Water Table, Zones of Aeration and Saturation, Confined and Unconfined Aquifers, an Aquiclude and an Artesian Water System.

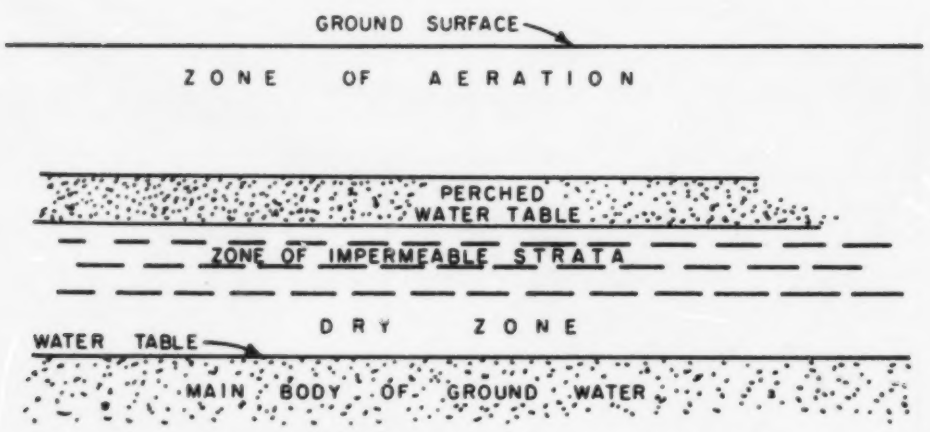


Fig.-3 – Diagram Showing Perched Water Table. *After Linsley (12)*

is to say, the water table has the shape of a flat inverted cone with its apex at the shaft. This is known as the cone of water-table depression or the cone of unwatering. Although in terms of strict geometry it is not a true cone, since its sides, viewed in cross section, are not straight lines but curves which steepen toward the shaft. The flow of water into the shaft is heaviest when pumping begins, but if sinking is stopped it gradually lessens and after some months becomes virtually constant. Accordingly, the cone of unwatering assumes a shape which is practically stable as the flow of water into the shaft reaches a state of equilibrium with supply of water entering the aquifer and percolating through it. If shaft-sinking is resumed, the process is repeated; the new cone is deeper and requires a higher rate of pumping to keep it drained.

If a drift is extended from the bottom of the shaft, the cone of unwatering is no longer a symmetrical cone; what was formerly the point of the cone is elongated into a horizontal line, the water table sloping upward from it at both sides and at the ends. If closely spaced crosscuts are driven from the drifts, the cone assumes somewhat the form of a bathtub with flat-sloping sides. If upper levels are now driven from the shaft they will

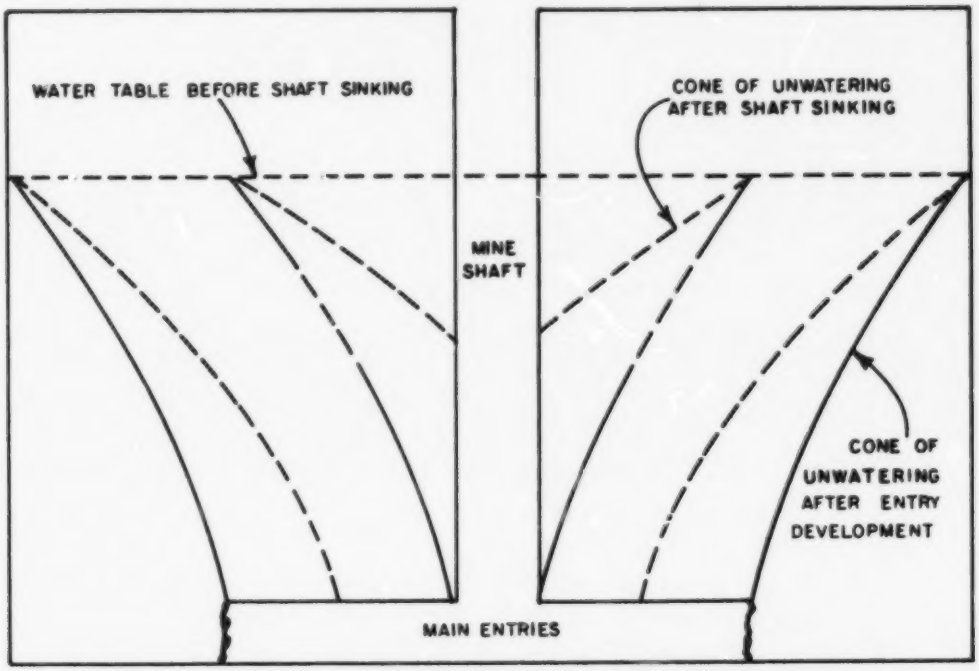
WATER TABLE BEFORE SHAFT SINKING
CONE OF UNWATERING AFTER SHAFT SINKING
MINE SHAFT
CONE OF UNWATERING AFTER ENTRY DEVELOPMENT
MAIN ENTRIES

**Fig. 4 — Diagram Showing Development of the Cone of Unwatering (Cone of Depression) As Mine Shaft and Entries are Developed.**

> encounter little water until they are out far enough to reach the sides of the cone; then they will begin to tap the water reservoir, but unless they extend for long distances they will not materially lessen the flow that enters the deepest workings."(15)

The creation of the cone of unwatering by shaft sinking provides artificial topographic highs and lows and allows for the flow of water into the mine when the shaft is sunk through water-bearing strata.

Core drilling(16,17,18) is a means of detecting water bearing strata, measuring water level and water movement and is increasingly recognized as a necessity for determining the economics of mining. Water levels and movement can be studied by plotting the core drilling data on water level contour maps, water level change maps and well hydrographs.(16)

One study(19) included the drilling of 28 bore holes and the use of 137 other private and public wells to determine the effect of deep mining

on ground water movement. This data was correlated with information gathered from seasonal and areal distribution of precipitation and concluded that:

(A) No two mines should be expected to be alike in environment, hydrology, source of pollution or treatment.

(B) Mining can affect speed, course and quality of water moving through the mining area.

(C) Mining accelerated the natural flow and hydrogeologic conditions already existing in the area basins.

(D) Water under pressure, as a result of flow through strata located at elevations above the mine workings, can enter the mine from all directions including the floor (see figure 5).

(E) The chemistry of the ground water depends primarily on the composition of the minerals with which it comes in contact.

(F) Water samples collected at different depths varied widely in quality. Waters at shallow depths were less mineralized than those taken at great depths.

(G) Base flow (ground water contribution to stream flow) of acid waters was attributed to storage and slow release of deep and strip mine waters in the ground. The percentage of mine drainage to total surface water drainage is greatest during periods of little or no precipitation.

(H) Inter-basin movement of drainage across normal ground water divides is produced by the effects of mining.

## Water Entrance Into Mines

During the construction or later development of many mines, water may be encountered in various quantities due to local conditions. Some mines[21,22] are dry, whereas in others the weight of water to be removed is many times that of the coal raised to the surface.

Water[13,23] may enter mine workings in several ways:

(A) From water bearing strata that is in contact with coal seams.

(B) By entering shallow mines from the surface.

(C) By entering through faults and fractures in coal seams and adjacent strata.

(D) By entering active sections from abandoned workings.

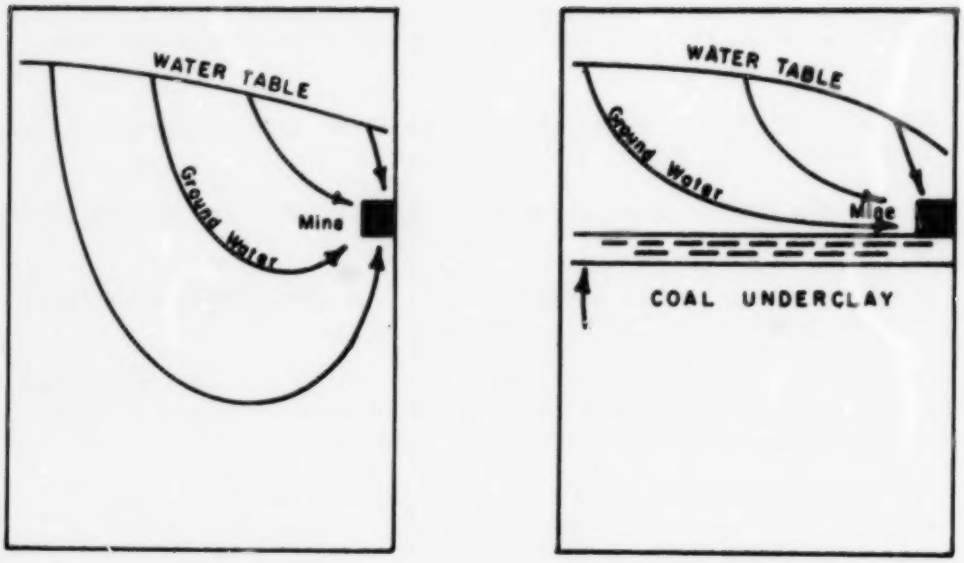


**Fig. 5 - Diagram Showing Idealized Movement of Ground-Water to a Mine Entry. *From Ward & Wilmoth. (20)***

Water Bearing Strata

Many of the rock beds associated with coal[13] are water impervious; however, sandstone beds in contact with coal seams may be very porous and transmit many thousands of gallons of water depending on the depth at which the porous beds are encountered. The deeper the location[12,22,24] of water bearing strata the less capacity the rocks have to transmit water due to the increasing pressure of the overlying strata.

Water in Shallow Mines

Strata near the surface will have different hydrologic characteristics than strata at depth and it is possible that shallow mines will encounter more water than deep mines.

> "It is comparatively easy for water to percolate to a certain varying depth as a consequence of the porosity of the surface rocks which are in process of disintegration by various natural agencies. Moreover, the rocks at limited depths are not subject to any great pressure and there

is little tendency to close up fissures and cracks once formed. At depths of less than 100 yards, seams are generally found very wet to work and storm water percolates rapidly into the workings. In these pits a marked difference is found between the quantity of water pumped in summer and in winter. These effects are emphasized if the beds outcrop in the vicinity of the mine."[13]

Water Entrance Through Fractures

Earth fractures[25,26,27], such as faults, joint systems in rocks, and fractures caused by surface subsidence allow water to enter underground mines in various quantities.

Many faults,[13] especially those that follow the strike of rock and coal beds, can act as main drainage lines and can yield large quantities of water when tapped by mine workings.

Joints in rock strata[16], formed by deformation of the strata, increase the porosity of otherwise impervious rock beds and may transmit water from overlying aquifers into mine workings.

Many studies and reports[13,21,27] on water drainage from mines indicate that mine roof fracturing and resulting surface subsidence after removal of mine roof supports, such as pillars and blocks, is one primary cause of water entrance into deep mines. Advance warning of fractures in the vicinity of the mining area is reported[16,23] to be best discovered by core drilling and construction of sub-surface structure maps.

Water from Abandoned Workings

Besides earth fractures and strata that transmit water, abandoned workings[13] that are broken into from active sections can cause large quantities of water to enter a mine. The[17] possiblity of guarding against this by carrying a long drill hole ahead of the working face, when it is known that abandoned workings are near, has been proposed.

## Geochemical Studies

Geochemical and stratigraphic studies of the distribution of sulfur and pyrite in relation to coal beds have received considerable attention. A study[28] that included a review of water analysis records on file at the Pennsylvania Department of Health, Division of Sanitary Engineering, was made of drainage from several coal beds and associated strata. The conclusion of this study is that there are variations in the composition of water discharged from various coal seams and that there are regional variations in water composition within single coal seams.

Other geochemical studies[29,30,31,32] have been conducted using specific coal seams to determine the distribution and depositional environments of sulfur and pyrite within coal seams.

The results of these studies have shown that it is possible to account for variations in drainage quality within a coal seam when the depositional environment of the coal seam and surrounding rock beds is known.

## SECTION V

## MINE WATER MANAGEMENT

In the past, mine management has been concerned with removing water from active mining sections primarily because it hampered the movement of mining equipment and aggravated the working condition of the miners. Pumping water to sumps and gravity drainage by ditching have proven successful in mines for minimizing section down time due to water influx. However, with the advent of more strict pollution laws the mining engineer must now be concerned with keeping water out of the section and also with preventing it from causing pollution. A review of the handbooks and textbooks used in the mining engineering curricula reveals that little has been written concerning acid mine water prevention or control in underground coal mines. Additionally, the review of the curricula of mining schools indicates they are not teaching the engineering students the necessary techniques of mine water management as they relate to the abatement of mine water pollution.

### Preventing Water Entry

The best way to reduce water problems is to prevent water from entering the mine, either by surface diversion or by underground diversion. The prevention of water entry is not an easy job nor one which conforms to a set formula. Due to the sequence of mining, topography, strata, and climate, it is difficult to predict the exact mining conditions to be encountered. Subsidence holes and faults increase the amount of water entering the mine, while close bonded rocks of high strength minimize seepage from overlying strata.

Subsidence which influences the inflow of water occurs only if the depth is relatively shallow (less than a few hundred feet). However, there are exceptions to this general rule due to the varying structure of the overlying rock and the general direction in which water flows over the subsided area. If the surrounding terrain drains into a subsided area, this could greatly influence the amount of water infiltration.

An examination of more than 250 mines in 1928 showed that the average rate of infiltration for all the mines came to approximately 1,100 gallons per acre per day.(33)

Parizek stated at the 1970 SME Fall Meeting that a more recent survey estimates the quantity of water leaking from the roof of underground mines to be approximately 670 gallons per acre per day.(34) These surveys indicate a range in the amount of penetration and it must be understood that these rates of infiltration may vary within any particular mine.

## Surface Diversion

Surface diversion is an important aspect to consider when dealing with the problem of water in coal mines. The use of diversion ditches and water rings (see Figure 6) can greatly decrease the water and ice problem encountered around shafts. Surface drains and waterways or flumes should be properly arranged to prevent waterlogging of the surface beds.

Seepage can sometimes be eliminated by lining the old drainage channels with concrete or bituminous coatings. A more permanent improvement, however, is to relocate the channel to non-caving or impervious ground.(35) In many instances where coal has been worked to the proximity of an outcrop, the amount of water that can infiltrate as a result of surface drainage will increase.

The Coal Industry Advisory Committee of ORSANCO has published case histories of mining practices(36) used to prevent or abate water infiltration into mines. Two cases dealing with water entry due to subsidence holes were designated No. 1a-12 and 1a-13, both of which deal with the Lower Kittanning coal seam in eastern West Virginia. The first case history involved an underground room and pillar operation where a subsided area, overlying a caved section that had been mined and abandoned, intercepted and diverted normal surface runoff into the mine. To reduce the total volume of mine discharge, the entire area, consisting of nearly an acre, was cleared. The weathered material was removed from within individual subsidence holes down to bed rock. The holes were then backfilled in 12 to 24 inch layers. Special precaution was taken to restore the original contour of the surrounding area. The water problem was successfully curbed. Although it was impossible to determine at that location, the control measure probably prevented the entrance of air into the mine (see figures 7 and 8). Under similar conditions, the vegetation should be restored with a combination of bushes, crown vetch and trees.

The second case history, No. 1a-13 reports on the success of using a water barrier compound for the sealing of individual surface subsidence holes. The subsidence was located in a wooded area with rocky terrain which did not allow for sufficient clearing and backfilling (see figure 9). A sheet of 3/32 inch butyl compound was placed in the cleaned-out hole and covered with compacted clay and dirt originally removed from the hole. Special care was taken to cover an area large enough to prevent water from getting under the butyl sheet and forming a trench to the original subsidence hole.

Since subsidence holes allow large amounts of water to infiltrate into the seam below, every precaution should be taken to prevent or cover these holes. It has been observed(37) that any excavation made in the mine releases the pressure above and allows the strata to flow in toward the excavation from all directions (see figure 10).

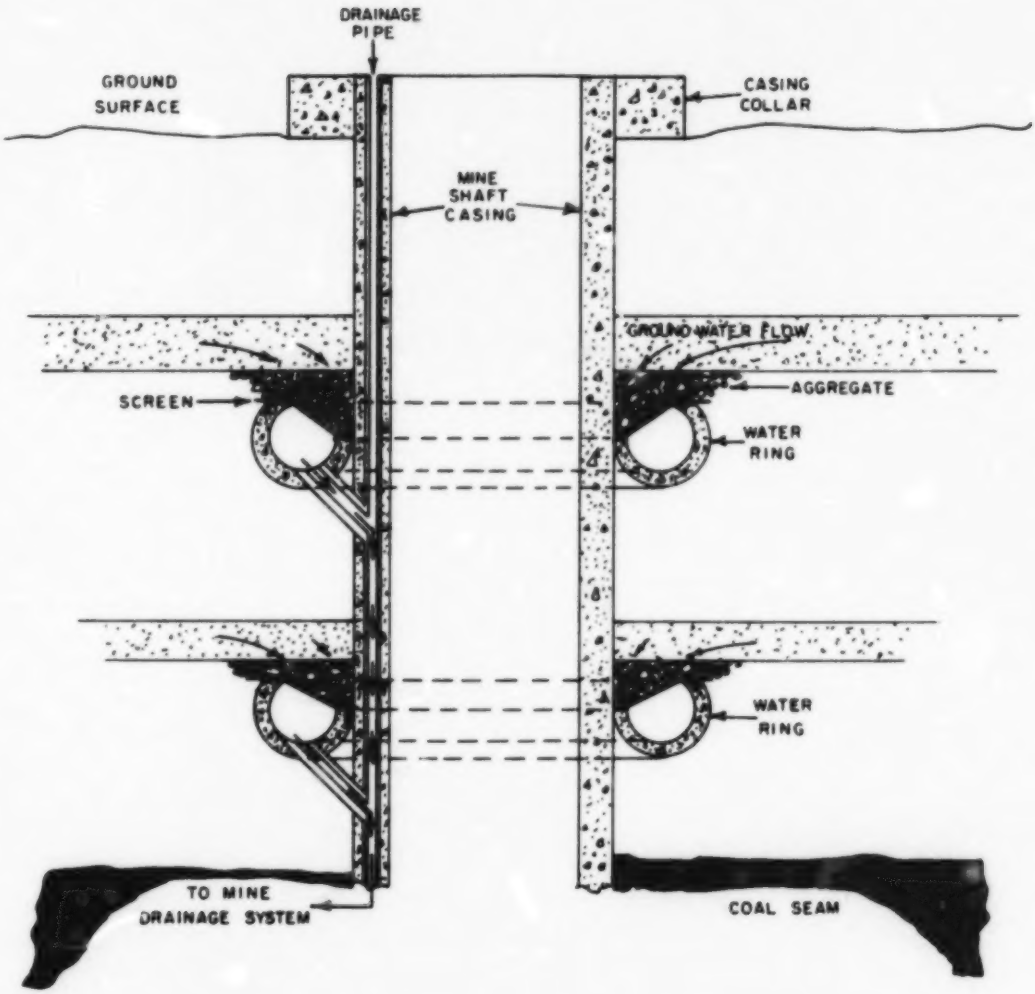


Fig. 6 – Idealized Cross Section of Coal Mine Shaft Showing Application of a Water Ring.

Fig. 7 - Surface Subsidence Single Hole. *(36)*

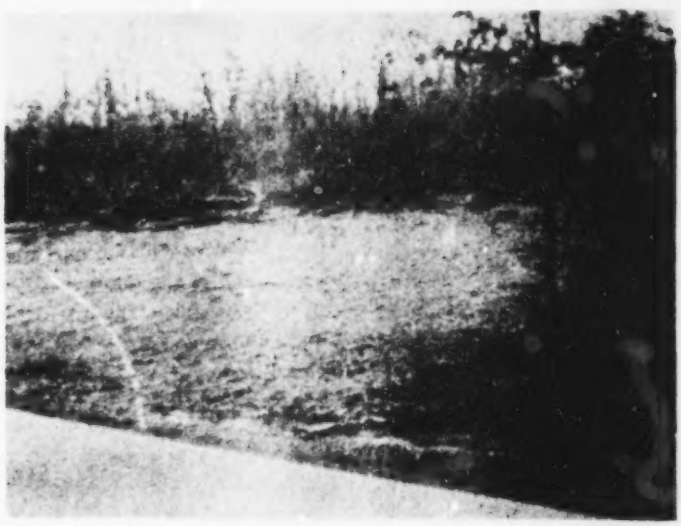

Fig. 8 ---Subsidence After Compaction and Regrading. *(36)*

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Fig. 9 – Subsidence Hole. *( Case History No. Ia –13. From Coal Industry Advisory Committee) (36)*

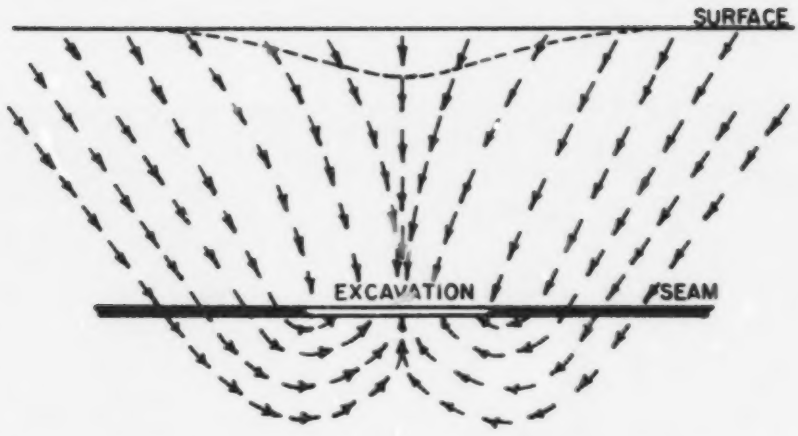


**Fig.10- Characteristic Lines of Ground Movement Around an Excavation. *(After Grond)*** (37)

Underground Diversion

It is not generally possible to totally prevent water from entering a coal producing area; therefore, some means of underground diversion must be considered.

In the course of mining, attention should also be given to prevention of crack formation under streams and rivers.(38) Sufficient coal can be left in those areas to prevent the formation of cracks to the surface. This usually means permanent support of the overburden and will require leaving from 30 to 60 percent of the coal at depths up to 400 feet. Since cracks to the surface are not usually formed at depths greater than 400 feet for beds up to 6 feet thick, many deep mines do not have this particular problem and complete extraction of the coal can be carried out without undue trouble from surface water.(39)

When extracting progresses near the boundry line a sizable barrier should be left, particularly if the seam is dipping away from the outcrop. Under such a situation, ground water will have a tendency to infiltrate into the coal seam and follow the dip. Sufficient barriers should also be left when mining adjacent to abandoned workings which might possibly be inundated with water.(35,40) The width of barriers to abate such water movement will depend on several factors such as angle of dip of the seam, the vegetation on or near the outcrop, and the adjacent strata. All factors should be considered separately for each mine and possibly for each section of the mine.

## Grouting

Another method of underground diversion is grouting. In 1891 Albert Francois[41] developed a method of sealing a shaft below the permanent water level by injecting a cementing agent into the strata under pressure. This grout was found to set and displace the surplus water. Cement worked well in voids and in fissured or fractured ground, but the process was ineffective in porous rock such as sandstone. It has been established experimentally that the width of voids in a formation must be at least three times the diameter of the grout particle in order to obtain effective penetration.[42]

The process of using a combination of cementation and silication helped to improve the effectiveness of the grouts. The chemicals employed in the process are aluminum sulfate and sodium silicate, used in dilute solutions with a gelatinous precipitate of aluminate silicate.[35] The new combination process proved highly satisfactory for reduction of porosity; and also proved advantageous because it formed a lubricant which coated the sides of the fissures and thereby facilitated the passage of cement.

The application or injection of the grouts could be used in shaft sinking to cut the infiltration of water or to stop it completely. The use of such agents, although widely accepted in other mining operations, should be investigated to determine economic and engineering feasibility for application in coal mining.

# Preventing Acid Water From Forming

Under most conditions it is neither possible nor practical to keep all water from entering a mine and contacting acid producing constituents of the seam and surrounding strata. The methods which may be used to prevent or minimize acid water formation are water removal and treatment of acid forming materials.

## Water Removal

The rapid removal of water infiltrating into a mine is most important in preventing the formation of acid water. Numerous studies by the Bureau of Mines,[43,44,45] have been made of the anthracite region where removal has been long recognized as a major problem. The anthracite region covers about 480 square miles and straddles two drainage basins--the Susquehanna and the Delaware, although the major acid water problems have centered around the Susquehanna basin.

Research was undertaken to develop a method for economic removal of water pools in the inundated reserves of the eastern field. Methods suggested were:[43,46] (a) the use of a drainage tunnel, (b) a central underground pumping plant, and (c) a deep well pumping plant. A comparison

| | Initial Cost | Pumping maintenance, etc., 13 years | Carrying charge, 3 percent | Total Cost |
|---|---|---|---|---|
| Plan A, drainage tunnel | $1,999,000 | Nil | $445,000 | $2,444,000 |
| Plan B, Underground pumping plant | 830,000 | $780,000 | 184,000 | 1,794,000 |
| Plan C, deep-well pumping plant | 577,000 | 689,000 | 125,000 | 1,391,000 |

Note: These are 1941 dollars and are presented merely to provide an order of magnitude comparison

Fig. 11 – Comparison of Costs for Three Drainage Plans. (USBM Bulletin 491, 1950) (46)

of costs for the proposed plans are shown in Figure 11. These costs, while obsolete, are presented as order of magnitude estimates only.

A 1941 report expressed the concern of the operators who were faced with the rising cost of pumping mine water in order to maintain mining operations. Underground water pools, some of which contained several billion gallons, were generally created by the inflow from adjacent mines which had inadequate barrier pillars, and also from the mines which were idle during periods of economic depression in the industry. The industry was, and still is, trying to control the problem by using central mine pumping stations equipped with centrifugal pumps.(45) Deep well pumps give satisfactory operating results and are used increasingly when and where conditions are favorable. In comparison with bituminous fields, the problems in the anthracite region were and are different. The work done in the anthracite region was concerned with quantity more so than with the water quality. The anthracite coal mining operators now find themselves handling a problem which is mainly concerned with the quality of the water.

## Treatment of Acid Forming Materials

If the entry of water cannot be avoided, it may be possible to prevent the air-water-pyrite contact by the use of silica gel and, to a degree, rock dusting of the exposed pyrite.

Sealants. Because of the needed reaction between pyrite, oxygen and water to form sulphuric acid in underground coal mines, it is believed that the development of sealants, to prevent the oxidation of pyrite as well as

to prevent contact with ground water, will greatly reduce the formation of acid water.[47]

One such substance for the prevention of acid mine drainage water is a sodium silicate solution.

The use of sodium silicate to prevent the formation of acid mine drainage was discussed[48] at the Third Symposium on Coal Mine Drainage Research and the following two applications were emphasized both of which depend upon saturating the strata in which the contaminating materials are formed:

A. The acidification of sodium silicate solutions resulting in the formation of stable, structurally strong gels. Once formed, such a gel could modify hydrologic patterns and exclude water from contact with the pyrite precursor and thus either prevent leakage from the strata or inhibit formation of the contaminants.

B. Alternately, the precipitation of ferrous (or ferric) silicate on the surface of individual pyrite, rocks, or soil particles to form an effective seal, insulating each entity from water.

The use of sodium silicate solutions has been tried only experimentally on gob or refuse piles as an Environmental Protection Agency (EPA) research project. The project, thus far, has shown only a potential value for silica gel application and more field experimentation is needed before its full value is known. The solution, if proven successful, could be used underground and injected into the floor and roof or coated on the ribs to abate the formation of pollutants.

Rock dusting. Rock dust is used in all underground coal mines to help allay fine coal dust and prevent the propagation of an explosion. Nothing can be found in the literature on the use of rock dust underground to treat acid mine water. Rock dust is mentioned here simply because it is an alkali substance (crushed limestone) and can, to some degree, neutralize acid water flowing through the mine. Its effectiveness, however, is limited. Rock dust will in some instances react with ferric iron compounds but the pH is not high enough for it to react with ferrous iron compounds. Therefore, its neutralization potential is very small and usually will not affect the discharge of acid water from underground coal mines.

## Underground Disposal of Acid Water

Recently, because of the attention surface waste disposal has received, the use of porous underground strata for disposal sites has become attractive to many industries. The use of disposal wells for acid mine water by the coal industry in Pennsylvania was the object of a study conducted by Pennsylvania State University, College of Mineral Industries, Department

of Mining.[49,50] The study concluded that the use of disposal wells for acid mine water is technically possible and the cost would probably range from $0.20 to $0.75 per thousand gallons of disposed water.

Although the process is reported as feasible, opposition has been raised by many state governments[51,52] and the Environmental Protection Agency of the Federal Government. The basis for this opposition arose from the results of experiments with deep well disposal systems at various locations in the country.

One experiment[51] was undertaken by the United States Army at the Rocky Mountain Arsenal, ten miles northeast of Denver. The well was completed in September, 1961, to a depth of 12,045 feet and the casing was cemented in place to a depth of 11,975 feet to protect more shallow fresh water aquifers. A total of 165 million gallons of liquid waste was injected into the well at an average rate of 200 gpm and 500 psi from March, 1962 till February, 1966. Shortly after the disposal operation began, a series of earthquakes were recorded in the Denver area and between April, 1962 and August, 1967, a total of 1,514 shallow depth earthquakes occurred.

Studies[53,54,55] made of the incident have concluded that the earthquakes were a product of reduced friction between layers of underground strata and along fault zones set up by the injection of waste liquids into the arsenal well.

An experiment[52] that resulted in pollution of surface water was conducted by the Hammermill Paper Company in Erie, Pennsylvania. The waste liquids were disposed of in a 1,610 foot well under pressures of up to 1300 psi over a period of four years. On April 14, 1968 the well top blew off allowing two million gallons of the waste to flow into Lake Erie before it was capped three weeks later. Corrosion of a casing joint was given as the reason for failure of the well.

An experimental drilling and disposal program was undertaken in southwestern Pennsylvania with a test well at the No. 58 mine of the Bethlehem Mines Corporation, a subsidiary of the Bethlehem Steel Corporation. Cores of the proposed area differed greatly in many aspects from those recorded at three nearby gas wells. The general lithology of the zone was quite complex, but could be approximated and is shown in figure 12. After recording the logs, there was a general feeling that the well was not as favorable as had been expected. The sandstone in the proposed disposal area was relatively thin and had a low porosity.

Although other factors also proved disadvantageous, it was felt that in view of the investment, the project should proceed with fresh water injection tests. The experimental well ran into numerous other difficulties and a decision to halt operations was finally reached when the pumping pressure reached 2,000 psi to simulate an injection of 150 gallons of acid mine water per minute into the well.

| Depth From Surface (feet) | Rock Description |
|---|---|
| 1302 - 1314 | Shale |
| 1314 - 1365 | First Salt Sand* |
| 1365 - 1428 | Shale and Siltstone |
| 1428 - 1518 | Second Salt Sand** |
| 1518 - 1547 | Shale with Minor Coal |
| 1547 - 1565 | Maxton Sand*** |
| 1565 - 1588 | Shale and Claystone |

*Interbedded shale, siltstone, claystone and minor sandstone (16 feet)
**Approximately 64 feet of sandstone with minor shale and siltstone.
***Entire interval sandstone.

Fig. 12 – General Lithology of Cored Interior of Disposal Well. (57)

Although Bethlehem's main purpose was to evaluate sub-surface disposal as a means of abating acid mine pollution, the investigation was halted before any acid mine water could be injected, and the amount of water pumped into the zone was not sufficient to determine the long term effect of this process. Additional information about this project is available through the Coal Research Board of Pennsylvania.(56)

The lack of knowledge of the complex geologic structures underlying much of the Appalachian coal fields and the potential pollutional effects that could result from deep well injection is the chief concern of those state and Federal agencies opposing this method of disposal of waste acid drainage.

## SECTION VI

## MINE CLOSING

Mine closing methods should be carefully considered. If not properly sealed, an abandoned mine may continue to produce acid water. Since 60 to 90 percent of the total acid discharged from all coal mines is from abandoned mines,[58] some states require that provisions for sealing be contained in the mining permit application. Closing an operation to prevent harmful mine drainage into nearby runs and streams is a subject of much concern to states as a result of continuing problems from long abandoned mines which were improperly closed.

### Mine Seals

It has been reported[59] that abandoned mines sealed by natural cave-ins produced less acid drainage than mines in the same locality that remained open. It was concluded that sealing of abandoned mines to exclude air would help prevent stream pollution.

Determining whether the mine level is above or below the water table will greatly influence the effectiveness of the seal. It has been observed[60] that effluents from mines above the water table do not show as good a water quality as those taken from mines which are below the water table and are inundated. One of the methods for abating pollution in the thirties[61] was construction of a large number of wet and dry seals. Although the seals were of some aid, most have now deterioriated and overall they have proved to be relatively ineffective.[62] It may be that the mines were too close to the surface and they may have contained many voids, faults, and subsidence holes which permitted air and water entry. Deterioriation of the cement is another reason that many of the older seals are now ineffective.

A typical wet seal consists ordinarily of concrete about 3 feet thick, extending into the ribs approximately 3 feet, and set deep enough into the floor to strike solid rock, which usually varies in depth from 18 to 36 inches.[59] The seals are generally flat or concave and have a short section of pipe to release excess water pressure or provide continual drainage. A wet mine seal and its installation requirements for a controlled flow are represented in figure 13. The effectiveness of sealing could be enhanced if the seals would be placed further back in the opening where the surrounding rock would be stronger and therefore better for anchoring the seal.

An in-depth study by the Halliburton Company for the EPA, which included laboratory and field tests, was undertaken. This study considered all phases of mine sealing.[63] One test examined the use of expendable grout retainers (figure 14), which are collapsable fabric bags. They are placed in the entry and filled with a grout slurry. The flexibility of the bag eliminates the time for building concrete forms and also



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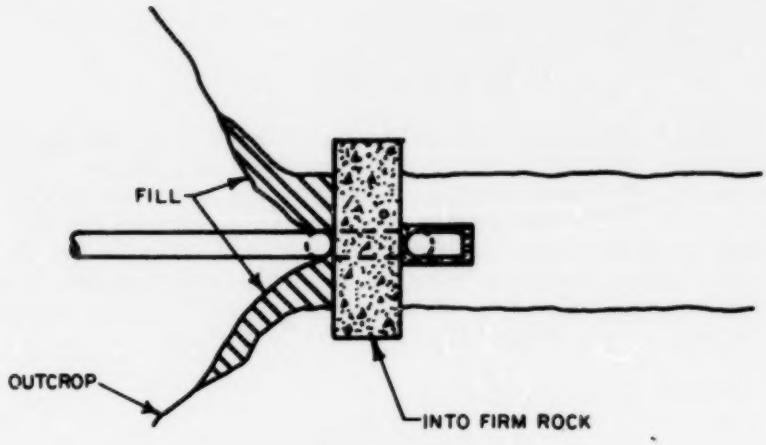
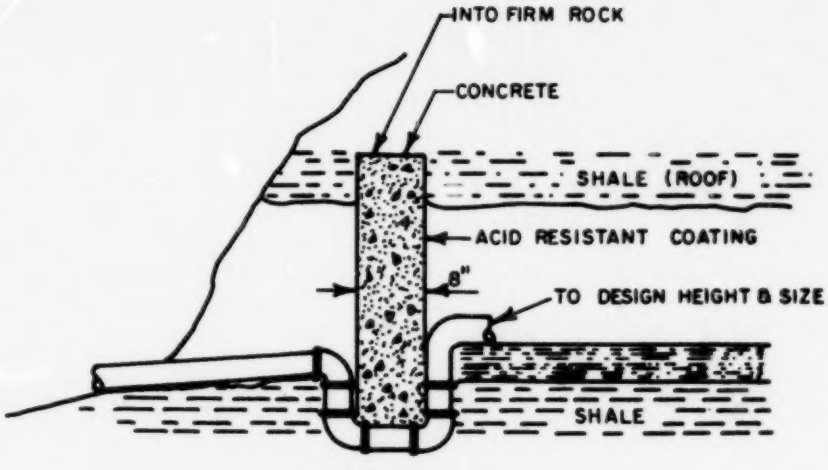



—PLAN—




—ELEVATION—

**Fig. 13 — Wet Mine Seal With Controlled Flow.** ***(Handbook of Pollution Control Costs in Mine Drainage Management, F.W.P.C.A.) (64)***

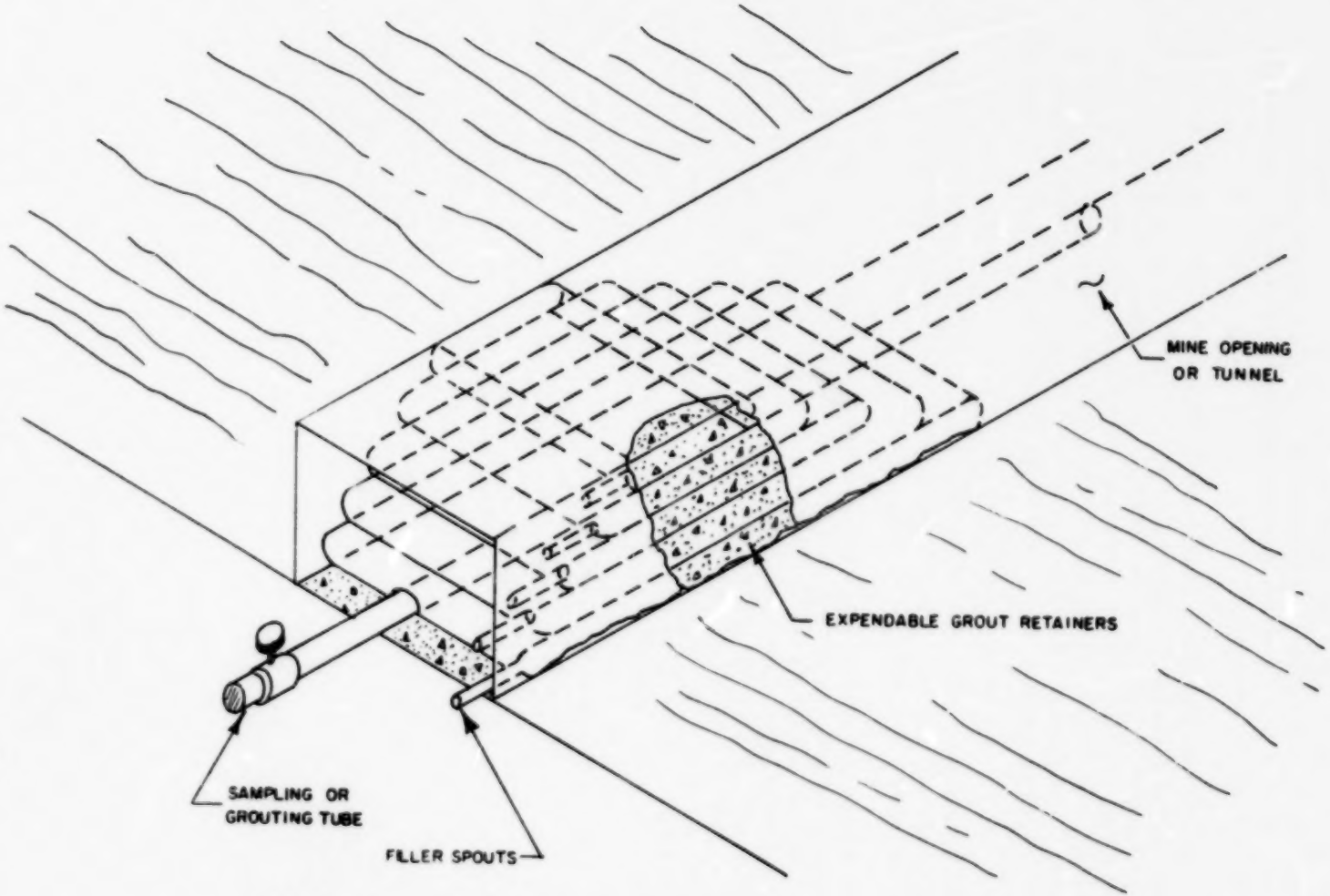



Fig. 14– Expendable Grout Retainers. *(63)*

eliminates the requirement for personnel to enter the mine to prepare the ribs, roof, and floor. The retainers may also be permeable as a means to permit a bond between the (a) retainer fabric and surroundings and (b) successive retainers.

Another abatement method examined by Halliburton to close drift mine openings involved using inflatable bags or packers located closely adjacent to each other along an entry so as to provide pneumatic forms between which grouting could be placed and permitted to harden to form bulkheads. Sealing is achieved when two sets of these bulkheads are completed at sufficient distance from each other so as to permit introduction of ample quantities of cement as a means to provide a substantial plug.

The use of ground aggregate proved to be more feasible in areas where the closeness of timbers and other permanent construction excluded the use of expandable retainers.

Another investigation by Halliburton employed a plug consisting of grouting as well as aggregate material of various grades or sizes pneumatically discharged near the roof of a mine at the desired location (see figure 15). This plug was constructed as follows. First, the mine roof, floor, and ribs were cleared of extraneous material to obtain a complete bond between the surface and the plug. Second, a bulkhead was deposited consisting of 3/4 to 1 1/2 inch graded limestone 30 feet back from the face of the opening. The bulkhead extended from wall to wall and from floor to roof, with a longitudinal base width of approximately 14 feet and a top width of 2 feet. Third, minus 3/8 inch aggregate was deposited on the face of the bulkhead to form a barrier for the grout. Fourth, 3/4 to 1 1/2 inch grouted aggregate was then deposited in the center section. Fifth, a layer of approximately one foot of minus 3/8 inch aggregate was placed over this to form an impermeable barrier. Finally, twelve inches of 3/4 to 1 1/2 inch aggregate was then deposited to form a protective cover and to bring the plug to its final length of 34 feet. Due to leakage of grout through the front and rear bulkheads, a flake cellophane material was added to the grout slurry to act as a bridge in more permeable sections. This proved to be effective in stopping leakage. Some drainage was also encountered from a bottom pipe but could have been avoided had a quick-setting chemical been used as a grouting agent. It was concluded that this method could be used to successfully close any drift mine opening without regard to posts or other obstructions.

## Inert Gas

The concept of using an inert gas to prevent oxidation of pyrite in inactive coal mines has been known for many years. Documentation exists to show[65] that a substantial reduction in the acid formed by pyrite in contact with water can be obtained when the amount of oxygen in the atmosphere is controlled, and that no acid is formed in an atmosphere consisting of 100 percent nitrogen or another inert gas. If the oxygen could be reduced to 0.4 percent or lower, the amount of acidity developed

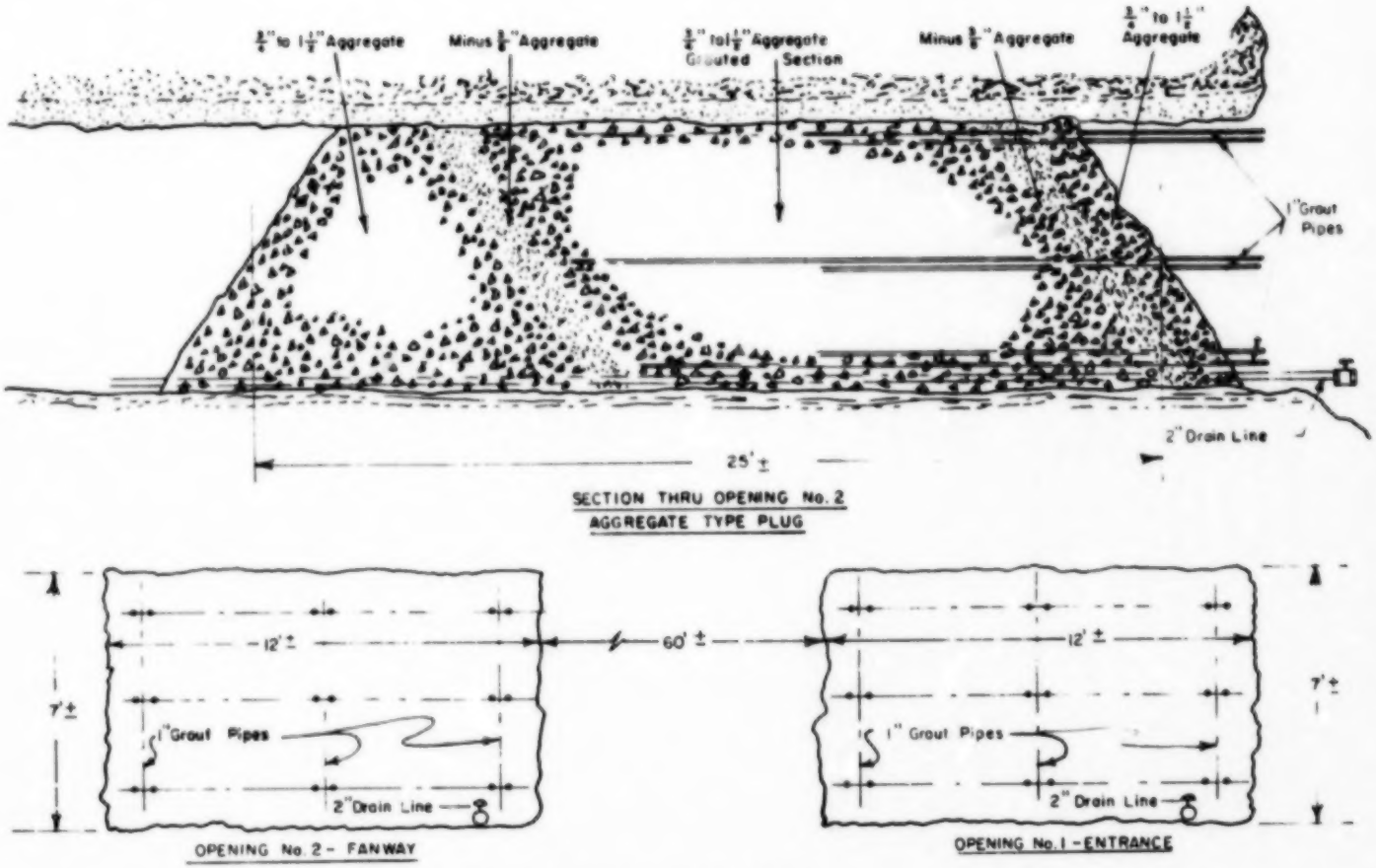



Fig. 15 — Aggregate Plug Detail. *(63)*

by the water and pyrite could be reduced approximately 97 percent over that occurring in air.

An inert gas atmosphere would be difficult to maintain due to the breathing that results from changing barometric pressure. A mine inhales when the barometric pressure is rising and will exhale as the pressure falls. Supplying an inert atmosphere to a deep mine must therefore be at a rate high enough to keep up with the inhalation requirements associated with the maximum rate of atmospheric pressure change. The choice of atmosphere is limited economically; nitrogen which costs approximately 60 cents per 1000 cubic feet would be very costly for even a small mine. For this reason alternative inert gas considerations led to the use of exhaust gases from an internal combustion engine.

With support from the EPA, a program was begun by the Pennsylvania Department of Mines and Mineral Industries to determine the applicability of introducing inert gas into abandoned deep mines. Initial work to determine major leaks in abandoned mines has shown the leakage rate is related to the length of outcrop. Although much work is involved in determining the leakage rate of inert gas, the potential for water quality improvement appears to more than offset this disadvantage.

## SECTION VII

## UNIQUE METHODS

Ever since the problem of mine pollutant waters has been under consideration, different mining methods have been investigated to abate the pollution problem.

Two such methods which have been reported are inert gas operation and revised mining methods.

### Inert Gas

Under a grant from EPA, a program[65] has been initiated to determine the applicability of an inert gas operation in an active deep coal mine. Island Creek Coal Co., the grantee, is responsible for developing a feasible mining method for mining coal in an inert atmosphere using space age technology.

The mine, referred to as the "Buck Rogers Mine," is to be designed to allow use of an all nitrogen, a nitrogen plus methane, or an all methane atmosphere. The use of an inert atmosphere will permit the recovery of methane gas that is released from the coal strata during mining operations. A large gassy mine is capable of producing up to 16 million cubic feet of methane a day. The recovery of methane gas can enhance the economic feasibility of this program.

There are many factors which are yet to be tested and many problems yet to be solved in such an operation; the life support system, extraction and transportation of coal, shafts and communication. If the inert gas mining method is perfected, and proves to be economical, it could solve three basic problems associated with mining; (a) removal of all or most of the oxygen to prevent fires and explosions, (b) prevention of oxidation of pyrite to form acid water, and (c) removal of men from exposure to dust, thus preventing miners pneumoconiosis.

It is anticipated that an experimental mine will go into production in the mid-seventies at which time the feasibility of such an operation will be determined.

### Revised Mining Methods

Often it is possible to design a mine such that the workings advance to the rise, giving an assist to haulage, drainage and sectionalizing the location of the water. A method in dipping seams is to work room panels down dip from strike entries on advance, and up dip on retreat.[66] Hence, the dip areas are worked before extensive mining occurs and such areas may be used as a primary or as a secondary sump for gathering local water.

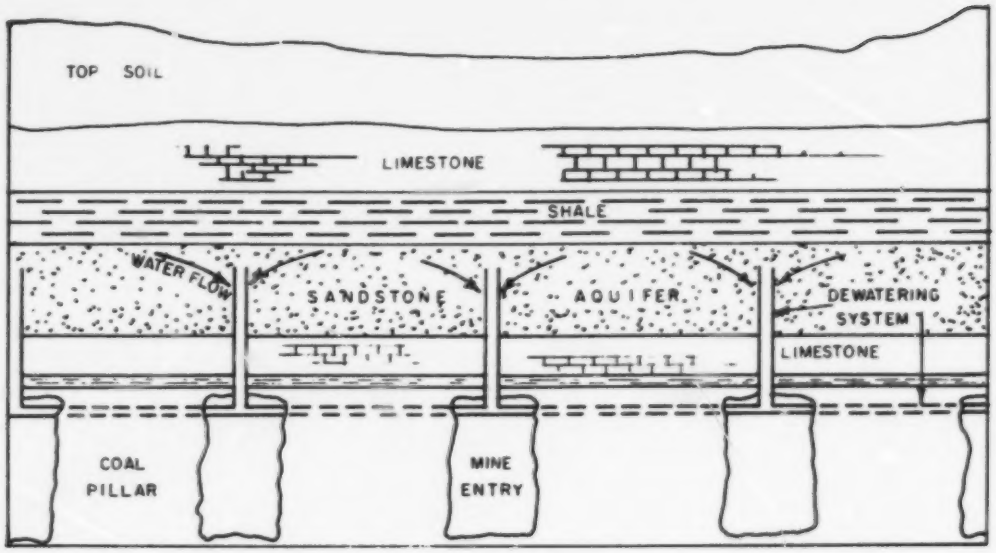



Fig. 16- Aquifer Dewatering System.

Another conceivable method[34] to reduce water inflow which employs hydrogeologic features involves the tapping of overhead aquifers and draining of some of the water before it can seep into the mining area. The aquifer could conceivably be tapped from either the surface, or in the mine, depending upon the depth of the coal seam and the aquifer. If tapped from the mine, the water could be removed through a pipe system to the outside or be retained for use in the mining operations. Such a system is illustrated in figure 16. If the aquifer is dewatered from above, the pumping stations would be located on the surface which would require additional capital investment and operating costs.

It is also possible to control extraction of coal in certain areas within mines in order to reduce infiltration of ground water. Pillars and barriers can be left in place if there is some possibility of intercepting large volumes of water. At outcrop lines and areas adjacent to worked out inundated mines, the barriers should be of more than sufficient size to keep water out while coal is being removed and to keep water in after mining has been completed.[67]

Little engineering information is available to the mining engineer concerning mining methods to prevent acid water formation. Such information would be helpful in the mine planning stage where decisions are made as to type of mining, size of pillars and type of equipment. Most mining textbooks, now obsolete, and handbooks consider only the problem of acid

water insofar as detrimental corrosion to pipes and pumps is concerned since this subject represented the major acid water problem of a few years ago. However, nothing is mentioned on the critical subject of water pollution from acid mine water.

## SECTION VIII

## RESEARCH NEEDS

This report was limited to a search of available literature on underground methods to combat acid water pollution. From this review it is evident that very little work has been done in this specific area. It is also evident that there are specific areas of mining engineering and mining related hydrology and geology that need further research efforts to solve the many water problems. They are:

(A) Composition, variation and availability for oxidation of sulfur in strata.

(B) Rate of oxidation of sulfuritic materials.

(C) In situ limestone and its influence on underground acid drainage.

(D) Structural, stratigraphic and hydrologic character of old mining areas as a basis to make decisions about adjacent new mining areas.

(E) Operational changes in mining methods to prevent pollution.

(F) Sealants for underground coating to exclude water from contact with pyrite to inhibit formation of the contaminants. Such a program has been initiated on refuse piles.

The prime purpose of this report is to investigate those practices which have been used to regulate or control water accumulation and prevent harmful mine drainage. A supplemental purpose is to indicate those areas which need further research to prevent underground mine water pollution.



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## SECTION IX

## ACKNOWLEDGMENTS

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## SECTION XI

## GLOSSARY

Acid - A substance containing hydrogen which may be replaced by metals with the formation of salts.

Alkaline - Having the qualities of a base.

Aquifer - A formation, or a group of formations, that is water bearing and water transmitting.

Artesian - Refers to ground water under sufficient hydrostatic head to rise above the aquifer containing it.

Barrier Pillar - A solid block or rib of coal, etc., left unworked between two collieries or mines for security against accidents arising from an influx of water.

Borehole - A hole made with a drill, auger, or other tools for exploring strata in search of minerals, for water supply, for blasting purposes, for providing the position of old workings or faults, or for releasing accumulations of gas or water.

Contour - A line drawn through points of equal value on a map or diagram, most commonly points of equal elevation on a map.

Core Drill - A mechanism designed to rotate and cause an annular - shaped rock - cutting bit to penetrate rock formations, produce cylindrical cores of the formations penetrated, and lift such cores to the surface, where they may be collected and examined.

Dip - The angle at which a bed, stratum, or vein is inclined from the horizontal.

Gob Pile - A pile or heap of mine refuse on the surface.

Grouting - The act or process of injecting a coarse kind of plaster or cement into a crevice of a rock, usually through a borehole.

Hydrograph - A graph to show the level, flow, or velocity of water in a river or channel at all seasons of the year.

Hydrology - The science dealing with water standing or flowing on or beneath the surface of the earth.

Outcrop - The part of a rock formation that appears at the surface of the ground. It includes those deposits that are so near to the surface as to be found easily by digging.



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Overburden - Material of any nature, consolidated or unconsolidated, that overlies a deposit of useful materials, ores or coal.

Pyrite - Iron disulfide, $FeS_2$; contains 46.7 percent iron, 53.3 percent sulfur.

Room and Pillar - A system of mining in which the coal or ore is mined in rooms separated by narrow ribs or pillars.

Silica Gel - Porous material consisting of pure silicon dioxide. Used as a dehumidifying and a dehydrating agent.

Strike - The direction or bearing of a horizontal line in the plane of an inclined stratum that is perpendicular to the direction of the dip.

Subsidence - The lowering of the strata, including the surface, due to underground excavations.

Topography - The physical features of a district or region, such as are represented on maps, taken collectively; especially, the relief and contour of the land.

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27 Abstract

This report is a review of published information concerning the abatement of harmful drainage from underground coal mines. Although much has been written on mine water management, very little literature is available on the specific area of preventing the formation of acid water. The references used in this report include mining engineering and hydrology studies an spans the period of time when water quantity rather than quality was the major consideration.

Physical approaches to the problem of interdicting water entry into coal mines, beyond removal and treatment, have only recently been undertaken. Some new approaches to this problem are (a) land management for surface and sub-surface water diversion, (b) the exploitation of water carrying strata, and (c) new mining methods.

Chemical approaches to abatement include (a) the use of silica gel solutions underground to prevent acid formation, (b) the use of inert gas in active mines and (c) the use of new and the refinement of known grouting agents.

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